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Northeast Region
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Woodstock, Vermont

Forging Changes in an American Landscape: Invasive Plant Species at the Saugus Iron Works National Historic Site

Technical Report NPS/NER/NRTR—2005/010

ON THE COVER
Phragmites: *Phragmites australis*
Photograph by: Christopher Davis

Forging Changes in an American Landscape: Invasive Plant Species at the Saugus Iron Works National Historic Site

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Acknowledgements

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Introduction

Systematic data collection and long-term monitoring of natural communities is essential for understanding and managing environmental threats. Without baseline data, current and future generations lack the ability to track changes to the environment (Pauly 1995). In the absence of long-term data, it cannot be determined if observed changes in the environment are catastrophic, unusual, or rare, nor to assess causation from human perturbations, disturbance events, or invasive species (Sebens et al. 1997).

The Saugus Iron Works National Historic Site (site) conducted an invasive plant survey during the summer of 2003 to generate baseline data in order to manage and assess the spatial impact of invasive plants. The primary goals of this study were to 1) determine which invasive plant species inhabit the site; 2) determine the percent cover and density of the dominant invasive plant species; and 3) map where the dominant invasive plant species occur within the site.

The NPS and the site are mandated to protect native species while at the same time controlling invasive species. NPS *Management Policy 2001* prohibits parks from permitting non-native species to displace native species when it can be prevented (section 4.4.4, *Management of Exotic Species*, in NPS 2001). Additional NPS policy states that "exotic plant species. . .will be managed - up to and including eradication - if. . .the exotic species interferes with natural processes and the perpetuation of natural features, native species or native habitats; or. ..disrupts the accurate presentation of a cultural landscape." The National Leadership Council's 1999 *Action Plan for Preserving Natural Resources* also addressed threats posed by non-native species and recommended that the NPS "act aggressively with a well-targeted effort to control non-native species" (NPS 1999). Goal Ia1b of Saugus Iron Works National Historic Site Annual Performance Plan (2003) is to improve resource conditions by containing the spread of invasive and exotic vegetation. In addition, park management will pursue further the scientific studies and professional analyses required to determine the scope, methods and feasibility of an appropriate treatment that would restore the appearance and biological health of the park's cultural and natural landscape (NPS 2003). In addition, Executive Order # 13112 requires that federal agencies must "prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts the invasive cause" (Federal Registry 64[25]: 6183-6186).

Global environmental change is detrimentally altering natural ecosystem function upon which all life depends (Mooney and Cleland 2001). The rapid increase in human population is the principal cause of recent global environmental change (McKee et al. 2003). Among the major threats posed by global environmental change are global warming, habitat alteration, resource depletion, pollution, and invasive species (Carlton 2000, Palumbi 2002). These global environment threats are not isolated in their impact on the natural world and can interact in a deleterious synergism (Agius 2003a). For example, global warming has dramatically increased the number of invasive species in native forests in the United States (Simberloff 2002). The loss of biodiversity around the globe is one of the most serious environment problems of our times, to only be exacerbated by the increase in the number of invasive species (Chapin et al. 2003).

While many exotic plant species introduced to new locations are not problematic or invasive in their home range, they often become severe problems in locations outside their natural range. These species have been described as alien, exotic, non-native, and nonindigenous, and those that are particularly aggressive are termed invasive. However, not all invasive plant species are exotic (e.g., in New England poison ivy is a native plant, but exhibits invasive growth), while some nonindigenous species are not invasive. In this report, the term "invasive" plant describes xenobiota (xenbiota are species that are both invasive and exotic [Carlton 2001]), while the term "exotic" is used to describe plants not native to New England (without indicating if growth is invasive or not).

Invasive species inflict immense ecological and economic damage on a global scale. A meta-analysis conducted by Pimentel et al. (2001) indicated more than 120,000 exotic species have invaded the United States (U.S.), United Kingdom, Australia, South Africa, India, and Brazil, causing $314 billion annually in U.S. dollars. Invasive species are represented in almost every taxonomic group; among the more notably destructive species are zebra mussels (*Dreissena polymorpha*), green crabs (*Carcinus maenus*), hydrilla (*Hydrilla verticillata*), feral cats (*Felis catus*), Indian mongoose (*Herpestes auropunctatus*), brown tree snakes (*Boiga irregularis*), wooly adelgid (*Adelges piceae*), cholera (*Vibrio cholerae*), gypsy moths (*Lymantria dispar*), and kudzu (*Pueraria lobata*).

The origin, cause, and vectors of invasive plant species invading new habitats are not always known. Many invasive plant species arrive accidentally by human transport (e.g., seeds in soils), while others are directly transplanted and cultivated as ornamental plants for landscaping and gardens before they escape into surrounding areas. Once established, invasive species endure natural growth and range expansion, often including dispersion by wind, water, and animals (Sakai et al. 2001). Birds in particular can carry seeds great distances, causing additional spreading of exotic species. Problems arise when invasive species occupy disproportionately large areas (high percent cover and/or density) in new locations, compared to their native counterparts. Many native species (plants and animals) are directly and indirectly displaced by invasive species. Not all exotic species successfully invade novel habitats after they are introduced. Some successful invasions require repeated introduction before the population is established, with the large amounts of genetic material and variation for populations to reproduce and grow out of control (Sakai et al. 2001).

There are several reasons why some exotic plant species become invasive. Many exotic plant species possess "weedy" attributes, including 1) fast growth; 2) disturbance tolerance (i.e., phenotypic plasticity); 3) high reproductive rates and output; 4) quick maturity; 5) early, late, and / or long reproductive periods; and 6) chemical defenses (Sakai et al. 2001). In addition to their aggressive growth, most invasive plants lack herbivores in their new habitats, which might otherwise keep populations in check (Keane and Crawley 2002).

Invasive species thrive in new habitats by escaping native controls formed in their original home range (Stokes 2001) and exploiting the native species and communities that cannot adapt quickly enough to deter their proliferation. Evolution is the process in which species develop through natural selection, traditionally thought to occur over long periods of time. Species have evolved to co-exist in natural communities, but the rapid transport of species around the world has disrupted natural evolutionary processes. Mounting evidence indicates that invasive species evolve rapidly due to additive genetic variance, epistatus, hybridization, genetic tradeoffs, specific genotypes, and genomic rearrangements (Lee 2002). Before the advent of rapid transport by humans, natural geographic (e.g., oceans and mountains) and climatic barriers prevented species from attaining pangenic distributions. Currently, international commerce transports thousands of species around the globe everyday (Carlton 2001), thus homogenizing the world's biota.

In some ecosystems, increased native biodiversity makes a natural community more resistant to species invasions (Stachowicz et al. 1999), while other ecosystems exhibit the opposite effect (Levine 2000, Lonsdale 1999). The discrepancy in ecosystems that support high numbers of invasive species with high native biodiversity is largely explained by co-varying extrinsic factors, such as propagule supply (Levine 2000, Lonsdale 1999) and niche opportunity (escape from predation, resource availability, and community maturity [Shea and Chesson 2002]). Once invasive species establish in an area, communities become subject to invasional meltdown, where initial invasions pave the way for the introduction of additional invasive species (Simberloff and Van Holle 1999). In addition, the loss of rare, native, species in communities may lead to invasive species becoming successful established (Lyons and Schwartz 2001).

Once viable populations of invasive plants become established in novel habitats, they inflict a suite of ecological damage to native species including loss of habitat; loss of biodiversity; decreased nutrition for herbivores; competitive dominance, overgrowth, struggling, and shading; resource depletion; and alteration of biomass, energy cycling, productivity, and nutrient cycling (Dukes and Mooney 1999). Invasive plant species can affect hydrologic function and balance, making water scarce for native species (Enright 2000). The loss of biodiversity around the globe is one of the most serious environment problems of our times and is exacerbated by the increase in the number of invasive species (Chapin et al. 2003).

A waterwort, *Elatine americana,* is a Massachusetts State-listed endangered aquatic plant that has been previously observed within Saugus Iron Works National Historic Site This species is protected under the State of Massachusetts Endangered Species Act (M.G.L.c.131A), its regulations (310 CMR 10.00), and the Wetlands Protection Act (M.G.L.c.131.s.40). Additionally, *Elatine americana* may directly benefit from the habitat protected at the site along with eradicating and/or controlling curly pondweed in the Saugus River. The detailed map of the primary invasive plant species in this report may provide important resources for the protection of native species and the control of invasive plant species within the park.

Materials and Methods

Systematic surveys were conducted to quantify the abundance and distribution of terrestrial and aquatic-emergent, invasive plant species, as well as the dominant native plant species at the Saugus Iron Works National Historic Site. No submerged aquatic vegetation was surveyed in this study, except for curly pondweed (*Potamogeton crispus*). The dominant native vegetation was recorded to determine if sufficient native plant material existed to recolonize sites naturally, following eradication of invasive species in a given area. The dominant native vegetation was categorized as trees, grasses, shrubs, and flowers.

Initial assessment of the problematic exotic plant species during the beginning of the project indicated 11 species as particularly invasive within the site (see Table 1 for list of species). These 11 invasive plant species (primary species) were mapped within the site, including their density and percent cover. In addition, 31 exotic plant species (secondary species) surveyed were quantified in terms of density and percent cover: however, due to time constraints, survey data for secondary species were not digitized (see Table 2 for list of species).

Table 1. List of the 11 primary invasive plant species mapped by creating polygons, quantifying the percent cover and density within each polygon.

Common name	Latin name	Common name	Latin name
Asian Bittersweet	*Celastrus orbiculatus*	Multiflora Rose	*Rosa multiflora*
Common Buckthorn	*Rhamnus cathartica*	Norway Maple	*Acer platanoides*
Curly Pondweed	*Potamogeton crispus*	Phragmites	*Phragmites australis*
Garlic Mustard	*Allaria petiolata*	Purple Loosestrife	*Lythrum salicaria*
Glossy Buckthorn	*Rhamnus frangula*	Tree of Heaven	*Ailanthus altissima*
Japanese Knotweed	*Polygonum cuspidatum*		

Table 2. List of 31 additional secondary exotic plant species surveyed. These species are designated as secondary exotic plant species, being surveyed within grid for percent cover and density.

Common name	Latin name	Common name	Latin name
Black locust	*Robinia pseudoacacia*	Oxeye daisy	*Chrysanthemum leucanthemum*
Broadleaf plantain	*Plantago major*	Periwinkle	*Vinca minor*
Buckthorn plantain	*Plantago lanceolata*	Privet	*Ligustrum* spp.
Bull thistle	*Cirsium vulgare*	Queen anne's lace	*Daucus carota*
Celandine	*Chelidonium majus*	Ragweed	*Ambrosia artemisiifolia*
Chicory	*Cichorium intybus*	Red clover	*Trifolium pratense*
Common Tansy	*Tanacetum vulgare*	St. Johnswort	*Hypericum perforatum*
Crab apples	*Malus* spp.	Teasel	*Dipsacus* sp.
Day-lily	*Hemerocallis fulva*	Toad flax	*Liniria vulgaris*
Ground ivy	*Glechoma hederacea*	Vetch *	*Vicia* spp.
Horse chestnut	*Aesculus hippocastanum*	White clover	*Trifolia repens*
Japanese barberry	*Berberis thunbergii*	Wild grapes *	*Vitis* spp.
Lambs quarter	*Chenopodium album*	Winged euonymus	*Euonymus alata*
Lilac	*Syringa vulgaris*	Woody nightshade	*Solanum dulcamara*
Mugwort	*Artemisia vulgaris*	Yarrow	*Achillea millefolia*
Mullien	*Verbascum thapsus*		

* denotes cryptogenic species (may be either native or exotic)

The systematic field survey was conducted from July 16 through August 14, 2003 to cover the site (see Appendix A for the site layout). The present boundary for the site, which includes the Saugus River and adjacent wetlands, encompasses 5.3 hectares (ha) (congressional boundary is 3.4 ha or 8.51 acres). The survey was conducted with a Garmin V GPS hand held unit plugged into a CSI MBX-3S differential receiver backpack. The Universal Transverse Mercator coordinate system (UTM), Zone 19, was used throughout the study for all GPS and GIS uses. To aid navigation and mapping, 1 meter (m), 1:5,000 scale, black and white digital aerial orthophotos (orthophotos) were used in combination with the GPS unit. The 1m black and white orthophotos where obtained from the MassGIS website (http://www.state.ma.us/mgis/) then reprojected into the UTM system.

To conduct the survey in a systematic fashion, grids were created using GIS software (ESRI ArcView 3.2) and were overlaid on the site, with 50m x 50m grids. Grids were saved in 'shapefile' format. The 50m x 50m (i.e., 0.25 hectare or 0.62 acre) grid was used to survey the entire site. Each of the 28, 50m x 50m, grid cells was assigned a unique ID number that was used for referencing grid cell locations.

During the survey, there were instances when a portion of the site was not covered by the grid, but those sections were systematically surveyed as well to cover the site in its entirety. Prior to field surveys, black and white maps were printed that included the grid layer with individual grid attribute ID numbers, 1-meter black and white orthophotos, site boundary, scale bar, and north arrow. Maps typically included a block of 4 grids per 8.5-inch x 11-inch page~~s~~, although other grid dimensions were used when necessary.

The grid shapefile was also uploaded into the GPS unit to aid in navigation. In the field, a piece of tracing paper was placed over the 2 x 2 grid map, and the corners of the grids marked for aligning the tracing paper with the grid map. The surveyor’s name, date, site, and grid numbers were recorded on the tracing paper.

Each grid was surveyed by walking the perimeter and then making transects (e.g., numerous transverse passes) within the grid until completely covered, with all targeted species quantified and mapped. Pinpointing locations in the field was done by referencing features on the ground (e.g., trails, roads, water bodies, trees, structures, fields, etc.) that were visible on the 1-meter black and white orthophotos; grid lines on the paper map; and the GPS tracks line, current position of GPS cursor, and grid lines on the GPS display screen. Using these references enabled the survey to be conducted with an accuracy of 1 meter or the margin of error produced by the GPS unit.

In the field, the 11 primary species were sketched onto the tracing paper using species-specific symbols in the exact location that they occurred in the field. In certain instances, there could be greater than 100 percent cover in a given location. Vertical stratification and overlapping of invasive species were prevalent and the vertical overlapping of invasive species was denoted by overlapping symbols on the tracing paper.
All the invasive species (primary and secondary) and dominant native species were recorded after completely surveying each grid cell. The density and percent cover of each

of the secondary exotic species and the four dominant native vegetation classes (i.e., trees, shrubs, grasses, and flowers) were recorded per grid cell, if present. The 11 primary invasive species were documented using discrete polygons in each grid cell which could be larger or smaller than a quarter hectare, with multiple polygons per grid. Polygons were mapped on tracing paper (hand-drawn) as contiguous and discrete patches for each of the 11 primary species as they actually occurred in the field. The percent cover and density of each primary species was quantified for each polygon.

Hand-drawn polygons created on tracing paper in the field were transferred into digital format using 'heads-up' digitizing capabilities of ArcView 3.2 (ESRI 1999). A separate shapefile was created for each of the primary invasive plant species with an attribute table containing the percent cover and density for each polygon. Species that occurred at low frequencies had smaller mean polygon sizes than common species. Patch sizes and polygon occurrences were somewhat subjective; being dependent upon methods used to survey and digitize the final polygons. For instance, because this study was conducted grid by grid, there was a tendency to break up large polygons across grid borders, so caution should be used when interpreting the number of polygons (Figure 1) and mean polygon size (Figure 2). Digitizing polygons without grid border breaks would decrease the total number of invasive polygons, thereby increasing the mean polygon size for some of the invasive species.

Once digitizing and data entry was completed, spatial analysis was conducted in ArcView 3.2. and Excel (Microsoft 2002) to generate the abundance and coverages of each of the 11 primary species. Creating separate shapefiles for each primary species enabled the percent cover or density to be displayed for each species but would not allow the calculation of the total overlapping area of all 11 primary species. To determine the area covered by overlapping polygon of all invasive plant species shapefiles in ArcView, raster data (as a bitmap) was exported from ArcView to SCION Image (version 4.0.2) for calculations.

The map for this report was exported from ArcView as a .JPG file to present the relevant invasive species data. The resolution of the final map (in JPEG format) does not reflect all of the data viewable in the ArcView layout. In addition, more data is contained in the attribute table of the ArcView files that is not shown in the JPG files. If finer resolution maps or additional data is needed, copies are available through the Natural Resource Manager at Saugus Iron Works Historic Site or the Database Manager at the Northeast Temperate Network.

Results

The infestation of invasive plant species made navigating the site extremely difficult and arduous. There were areas of the site in which four of the primary invasive plant species occupied a single 1m^2 vertical column (e.g., occupying the canopy, lower trees, shrubs, and ground cover layers), as seen in Appendix A. Digitizing the field maps of the 11 invasive plant species yielded 128 discrete polygons (Figure 1). There was little variation within the mean polygon size of each primary species (Figure 2), but some species had few occurrences (Figure 1).

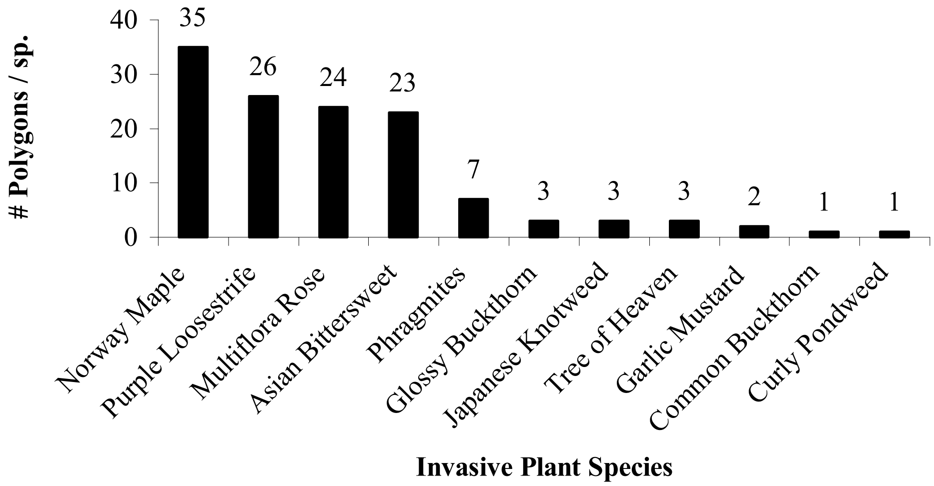

Figure 1. The number of polygons digitized for each of the 11 primary invasive plant species.

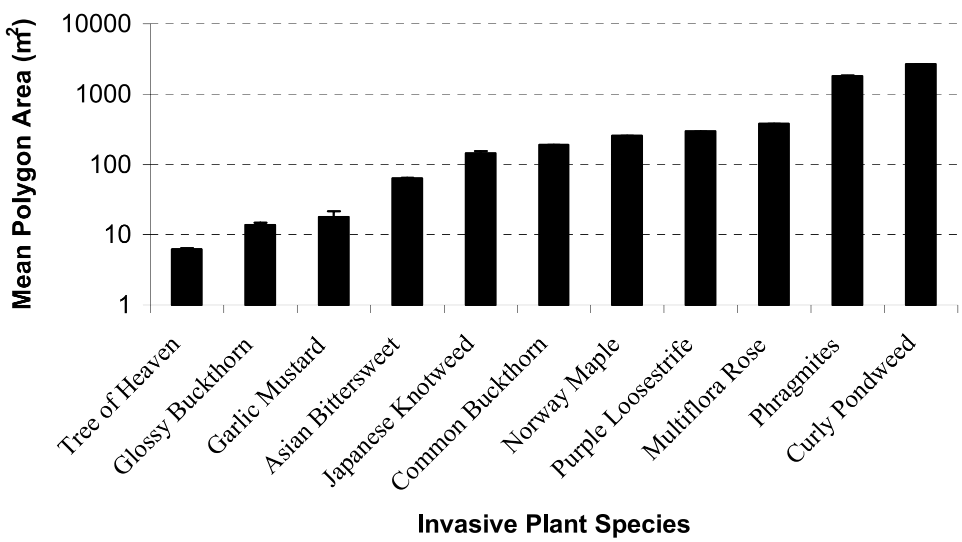

Figure 2. The mean area (m^2) per polygon for each species. Variance is presented as ± SE.

The additive area covered by all the 11 primary invasive plant species if distributions did not overlap is 4.3 ha or 81.5% of the site (Figures 3). However, there was vertical stratification within habitats (canopy, lower trees, shrubs, and ground cover). In other words, invasive species overlap are invading in a three dimensional fashion. The site is 59.1% covered by the 11 primary invasive species (Appendix A) when viewing the species as they actually overlap in the site. However, the survey area included approximately 0.9 ha of developed areas (pavement and structures). Subtracting the developed areas from those surveyed indicates that 72.3% of available natural habitat is inhabited by the 11 primary invasive species.

Phragmites was documented at the most problematic invasive plant species within the site. On a logarithmic scale (Figure 3), *Phragmites* is in the same order of magnitude as the scale of the entire site. At 1.3 ha, *Phragmites* dominates 29.1% of the undeveloped habitat in the site.

The site's second largest infestation (0.9 ha) is caused by multiflora rose. It has invaded nearly the entire under story of the mixed successional forest habitat east of the Saugus River, at the site. Multiflora rose grows as a vine, with large thorns, and forms impenetrably dense thickets. At 0.9 ha, multiflora rose dominates 20.8% of the undeveloped habitat at the site (Figure 3). The mixed succession forest habitat within the site is dominated by Norway maple, a hardwood tree forming much of the site's forested canopy. Norway maple was the third largest infestation, at 0.89 ha (Figure 3), or 20.5% of the undeveloped habitat at the site (Figure 3).

The combined acreage of *Phragmites* and multiflora rose (2.16 ha) totals more than the 9 other primary species combined (2.15 ha). For the five smallest infestations, the combined areas of tree of heaven, garlic mustard, glossy buckthorn, common buckthorn, and Japanese knotweed equate to only 1% of the site surveyed (Figure 3). The appendix at the end of this report show the abundance and distribution of all of the 11 primary invasive species mapped during this survey (Appendix A).

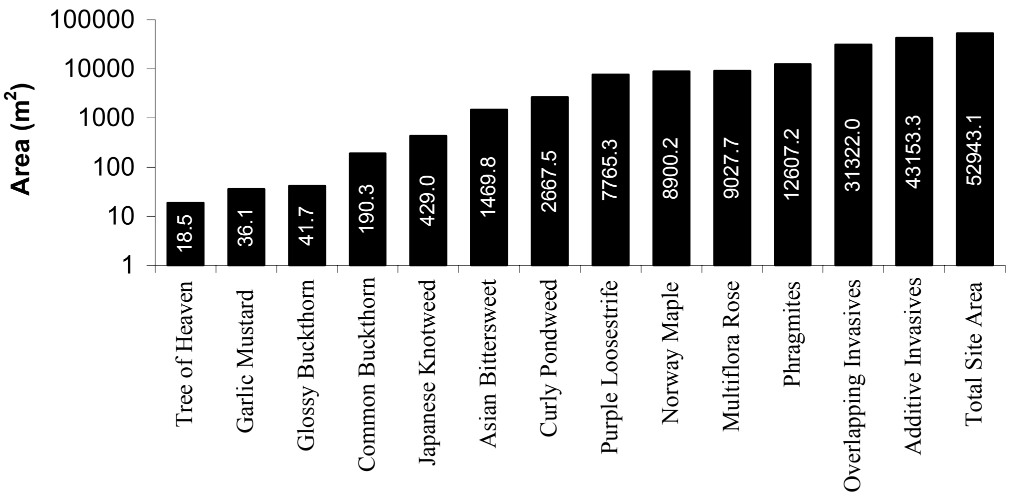

Figure 3. The area (m^2) for each primary invasive species, their totals, and site area on a logarithmic scale.

The 11 primary invasive plant species leave only 26.7% of the undeveloped habitats unoccupied for other plant species. That is not to say that native species do not occur within the mapped invasive areas. The natives plants also occupy three-dimensional habitats (in discrete vertical layers), and there can be greater than 100% cover in a single area that supports various species within vertically stratified habitats. Unfortunately, the 72.3% area of the primary invasive plants underestimates the total area inhabited by exotic/invasive plant species. There were an additional 31 secondary exotic plant species that were systematically recorded in this survey (Table 2). The 26.7% of the undeveloped habitats not covered by the primary invasives quickly dwindles when factoring in the dominant secondary exotic plant species and the secondary exotic plant species list did not include all of the exotic plant species found in the site. In addition, only curly pondweed was looked for in the submerged aquatic vegetation of the site, and there are likely many more exotic submerged aquatic plants inhabiting the site.

Furthermore, recently mowed lawns posed a problem in identifying species, presenting another source for underestimating the full extent of coverage by invasive and exotic plants. The National Vegetation Classification survey (Agius 2003b) at Saugus Iron Works indicates 1.39 ha (36.9% of the terrestrial and emergent aquatic vegetated area) of the site is comprised of *Dactylus glomerata* and *Rumex acetosella* herbaceous vegetation (e.g., grassy lawn habitat). It should be noted that lawns were comprised mostly of non-native grasses, and covered in numerous exotic small flowering plant species (e.g., silvery cinquefoil [*Potentilla argentea*], etc.), further increasing the area of the site inhabited by exotic and invasive plant species. Frequent mowing alters the morphology of these plants, making them difficult to identify until they flower. Exotic plants and grass species in the landscaped and mowed lawns of the site were not systematically quantified during the survey.

Discussion

Saugus Iron Works NHS was severely infested with invasive, exotic plant species during the time of this survey (2003). A small percentage of the site's undeveloped habitat remains devoid of invasive and exotic plant species. This survey identified the major problematic species and created a permanent baseline record of the abundance and distribution of the 11 primary invasive plant species for the summer 2003.

Phragmites was the most common and widely distributed primary invasive plant in the site. *Phragmites* is a tall perennial reed (reaching 4m in height), tolerant of a broad range of hydrologic conditions at the site. There was a native *Phragmites australis* in North America 150 years ago, but the current invasiveness of the plant is due to a non-native genotype introduced from Europe (Saltonstall 2002). *Phragmites* primarily spreads by vegetative rhizome growth (New England Wild Flower Society 1998), as seen in the dense stands around the site.

Physically altered habitats create ideal conditions for some invasive species, such as Asian bittersweet (*Celastrus orbiculatus*), a climbing and strangling vine. Asian bittersweet thrives in disturbed soils where its seeds are able to germinate, but the seeds only have a successful dormancy of one to two years (Ellsworth 2003). The growth characteristics of Asian bittersweet enable it to climb trees, which become overweighted and topple during heavy winds, thereby creating conditions (e.g., light gaps) suitable for the germination of additional Asian bittersweet plants. Birds disperse seeds of Asian bittersweet, as well as humans for landscaping projects (The Nature Conservancy 1984). Asian bittersweet's advantageous growth is documented the sixth most abundant primary invasive plant in the site (3.4% of the undeveloped habitat).

Undoubtedly, the historic conditions of the park have facilitated the proliferation of invasive plant species. The area has been extensively altered by humans for hundreds of years. It may be a mute point since no causation can be assessed without historic data on the species abundance and distribution and specific land uses prior to this study.

However, the negative impact that invasive plants inflict on native species has been and continues to be researched. Across large areas of the Northeastern U.S., European purple loosestrife (*Lythrum salicaria*) is becoming a dominant and destructive invasive species in wetland habitats. The site is no exception, with 17.9% of the undeveloped habitat occupied by purple loosestrife. This noxious perennial weed produces roughly two million seeds plant $^{-1}$ yr $^{-1}$ (Weatherbee et al. 1996) – a testament to its large reproductive output and aggressive ability to infest of wetland habitats. Purple loosestrife has been shown to reduce the biomass of the native cattail (*Typha latifolia*), leading to local extirpation of cattails (Weihe and Neely 1997) and other plant species.

Empirical evidence increasing indicates invasive plant species negatively affect native plant species. For example, the invasive garlic mustard (*Alliaria petiolata*) causes the mortality of the native cabbage butterfly larvae, if the eggs are oviposited on the plant

(Renwick et al. 2001). Garlic mustard is also displacing native plant species the cabbage butterfly depend on for feeding and reproduction. Thus, there is a two-fold negative impact of garlic mustard on cabbage butterfly; it out competes the preferred plants and causes mortality of larvae if eggs are laid on the ever increasing population of garlic mustard plants.

It is clear that significant negative impacts are generated by invasive plants on native species. Immediate measures need to be undertaken to control the invasions underway and thwart new species from infesting the park.

Management Recommendations

Although *Phragmites* is the most pervasive invasive plant at the site, management efforts should not focus on this species first. Instead, initial efforts should focus on eradicating the following five invasive plant species: 1) tree of heaven; 2) garlic mustard; 3) glossy buckthorn; 4) common buckthorn; and 5) Japanese knotweed, based on their relatively lower number of polygon occurrences (Figure 1), small mean polygon size (Figure 2), and overall acreage in the site (Figure 3). Tree of heaven, garlic mustard, glossy buckthorn, common buckthorn, and Japanese knotweed have been identified as extremely aggressive plants and detrimental to native communities in other locations in Massachusetts (Agius 2003c; New England Wildflower Society 1998). Targeting these five species could provide successful eradication of problematic species before populations have expanded and invaded additional areas.

The Saugus Iron Works National Historic Site is a small property (5.3 ha) and may be able to completely eradicate all invasive species present. Recent evidence indicates that eradication of invasive species is more advantageous than continuous biological, chemical and mechanical control (Simberloff 2001). However, the small size of the site contains disproportional large infestations of invasive species that may require most of the undeveloped site to be cleared and restored. Little native species biomass would be left after removing all of the invasive plant species, which would functionally alter the benefits native species provide to the natural community. Large scale removals of invasive plants often introduce enormous secondary impacts to the native species and open the door for future, and continuous invasions (reviewed in Zavaleta et al. 2001). Nevertheless, swift action most be taken to manage invasive species, while at the same time protecting native species.

Eradicating species when populations are small (both in size and number) is a better use of time, money, and effort than trying to control species that are well established, since small patches can quickly grow and act as a seed source for new populations (Simberloff 2003). Controlling species with low numbers of polygons, small mean polygon sizes, and small overall area in the site also requires less intrusive eradication techniques, including release of smaller amounts of herbicides into the environment and minimizing disturbance to habitats and native species.

This study documented and quantified the abundance and distribution of the invasive and exotic plant species. The management ideas are suggestions based on the data collected, the known threats of these invasive plant species in other locations (Pimentel et al. 2001; Renwick et al. 2001; Weihe and Neely 1997), and the literature on invasive plants (D'Antonia and Kark 2002; Mooney and Cleland 2001; Simberloff 2003). Based on the spatial distribution of the invasive plant species at the site, management can also use the estimates of native vegetation cover to determine if native plants can re-establish themselves in eradication areas or if replanting of native species is appropriate. Future projects should analyze the secondary exotic plant species, prioritize the species according to their threats to the site (spatial distribution, growth, and reproductive output), and conduct additional surveys of species which pose additional ecological threats to native species. Invasive plant species need to be addressed at scales that exceed site boundaries, because adjacent areas may act as seed banks for continuous invasions into the site. Since reinvasions may occur, the site may never rid itself of invasive plants if efforts are not made to collaborate with adjacent landowners to manage their areas too. Regardless of long-term success, management of all the invasive species is necessary (Simberloff 2003).

Not only does the site need to collaborate with adjacent and local property owners, it also needs to invest in more boundary markers being posted that are visible to those outside the site. In many areas, no boundary markers were able to be found. Without easily located boundary markers, how can it be expected for private citizens to know where the site boundary lies? In addition, the site needs to conduct a high resolution boundary survey with GPS to accurately account for and delineate the site boundary and have appropriate GIS boundary layers created for future survey work.

In conclusion, Saugus Iron Works National Historic Site will serve the public and the site's endangered waterwort *Elatine americana* well with swift control of its invasive and exotic plant species. Not only does the large infestation of invasive plant species within the site pose continual spread and increased density and percent cover, it is also serving as a seed source of invasive plant species invading areas outside of the site property. Adopting the management of invasive plant species outlined in this report will help in prioritizing invasive plant eradication and restoration projects, as well as thwarting new invasions. The site and its neighbors will mutually benefit the control of its invasive and exotic plant species, and as serve a model for environmental stewardship in the 21st century.

Additional Suggestions for the Park to Control Invasive Plant Species

1) Encourage and support academic research projects to investigate impacts to native species inflicted by invasive / exotic plant species on park property.
2) Promote and support volunteer invasive plant removal projects within and outside the park.
3) Establish an education program and displays about the threats posed by invasive species, and offer ways that individuals can contribute to eradication and restoration of native species. For instance, what species have been lost and which have invaded since the establishment of the original iron works?
4) Use only native species for all restoration and landscaping projects.
5) Focus on early detection and hand removal of new individuals and populations of invasive species, rather than chemical applications and biological controls.
6) Immediately remove any invasive species from the gardens and landscaping, regardless of their aesthetic value (e.g. privet, Japanese barberry, winged euonymus, tansy, etc.).
7) Conduct a systematic survey to map submerged invasive aquatic plants

8) Ensure the facilities management knows the threats of the exotic and invasive plant species and the identification of these plants. Facilities management is the park's first line of defense in many areas. They should be trained appropriately to remove invasive and exotic plant species when they encounter them. For example, effort should be made to clear out underneath trees instead of just around them.
9) Re-survey to monitor invasive species that may colonize new areas and to assess effectiveness of controls, eradication and restoration.
10) Analyze the secondary exotic plant species to establish which species pose the greatest threat at the park. Then, complete subsequent, detailed surveys that include those species that pose the largest risk as was done with the 11 primary invasive plant species in this report.
11) Procure funding for eradication projects, to be conducted by outfits such as the Exotic Plant Management Team.
12) Conduct additional studies based on the data generated from this survey, such as:
    - Does Norway maple facilitate the presence of garlic mustard?
    - Do invasive habitats alter behavior, nesting, or feeding in native birds versus native habitats?
    - Can floodplain maps model the distribution of invasive wetland species (purple loosestrife, and *Phragmites*) at the site?

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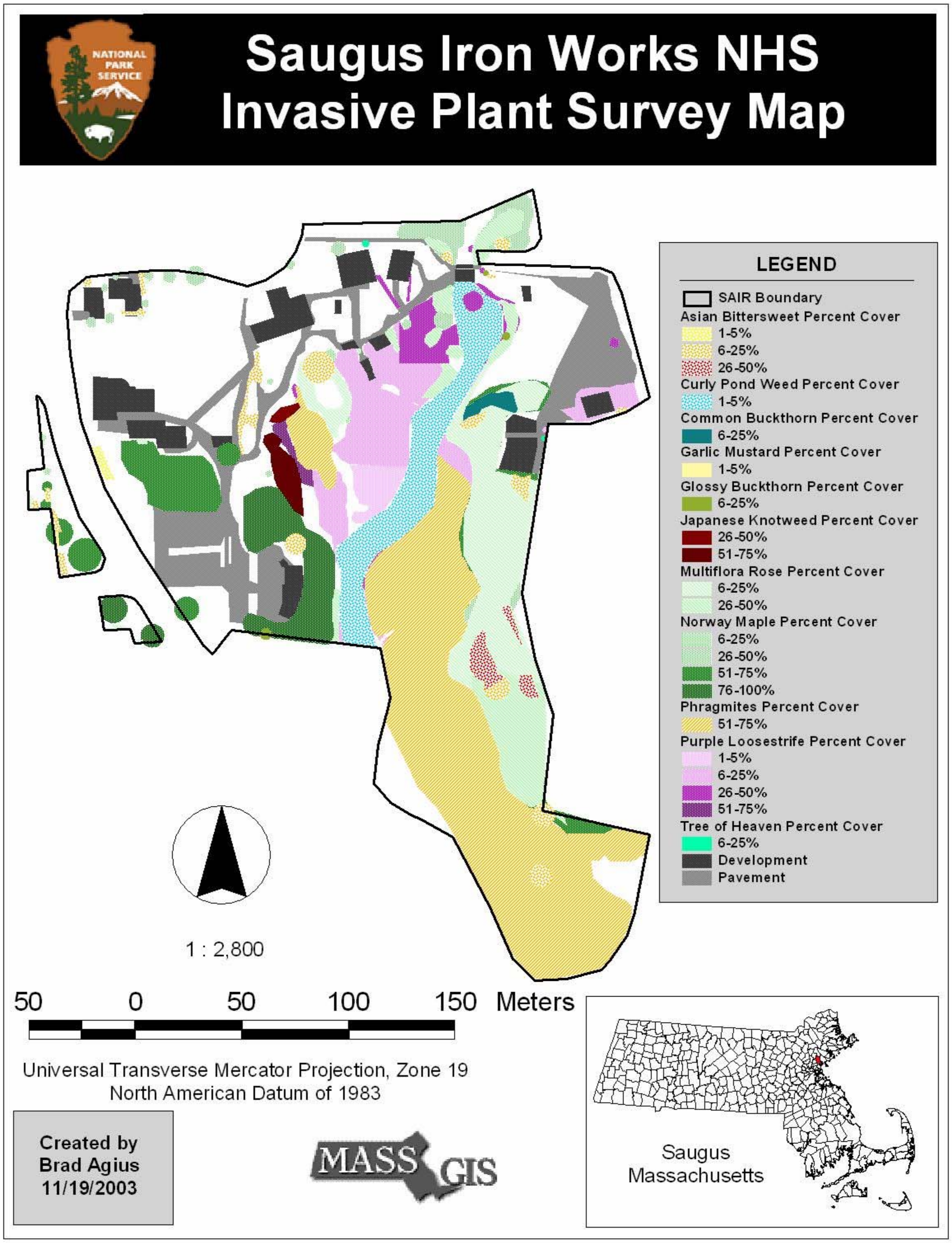
Appendix A. Saugus Iron Works National Historic Site Invasive Plant Survey Map with all Primary Invasive Plant Species.



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